Low-Speed Pressure-Sensitive Paint Research

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Pressure-sensitive paint (PSP) is a relatively new measurement technique used in aerodynamic wind tunnel testing. PSP contains a unique sensor molecule that can be excited with light that has an appropriate wavelength. The excited sensor molecule returns to its original state by re-emitting light, or by reactions with nearby oxygen molecules in a process known as "oxygen quenching." The emitted intensity of excited PSP is therefore directly proportional to the local partial pressure of oxygen and hence to the local pressure at the painted surface. Scientific grade charge-coupled device (CCD) cameras are used to record digital images of wind tunnel models painted with PSP. Images are taken with the wind tunnel running and with the wind tunnel turned off (this latter image serving as a reference). Software is used to calibrate the ratio of the wind-on and wind-off image intensities to pressures at various points on the model sensed by conventional pressure taps. Since the intensity-versus-pressure relation is (ideally) linear, only a few pressure taps are needed for proper calibration.

The use of PSP offers a dramatic process improvement in design and testing. PSP provides the capability to record the complete pressure field over a model surface with high spatial resolution. Wind tunnel models can be constructed with only a few pressure taps instead of the thousands of taps typically needed for structural load modeling. This saves precious design-cycle time that would otherwise be spent in constructing a complicated model.

PSP measurements are typically performed at Mach 0.2 or higher. Below these speeds, the intensity changes of the paint (as caused by pressure differences) become relatively small. External factors then interfere with the ability to accurately detect such minute signals. These factors include temperature effects (PSP intensity is also unfortunately influenced by temperature changes), registration errors between the ratioed wind-on and wind-off images, and electronic noise within the CCD camera.

However, PSP measurements at speeds below Mach 0.2 are of potential value. It is in this speed realm that measurements using PSP would be valuable to designers of vertical/short takeoff and landing aircraft, small-scale unmanned air vehicles, and automobiles. Experiments are being conducted at Ames Research Center using PSP on aerodynamic models at low speeds in an effort to further quantify measurement constraints and improve low-speed measurement techniques.

PSP experiments have been conducted in a 12- by 12-inch research wind tunnel on a NACA 0012 airfoil. Data have been obtained in a speed range of 10 to 50 meters per second (equivalent to 22 to 112 miles per hour).

The sources of errors inherent in PSP testing were minimized in an effort to obtain good response in this low-speed test regime. Data acquisition procedures were implemented to allow temperatures to properly stabilize on the model, thus minimizing temperature changes on the model and thereby reducing the effects of temperature-induced errors. A new camera-lighting stabilization mechanism was built that substantially reduced the model movement relative to the imaging equipment. Data averaging methods were applied to reduce electronic CCD noise.

Using the above technique, PSP measurements have been made, with good results in the 10-to-50-meter-per-second speed range. The calibration errors between the PSP pressures and tap pressures are very close to the current theoretical limits of PSP accuracy, and they are among the best currently published.

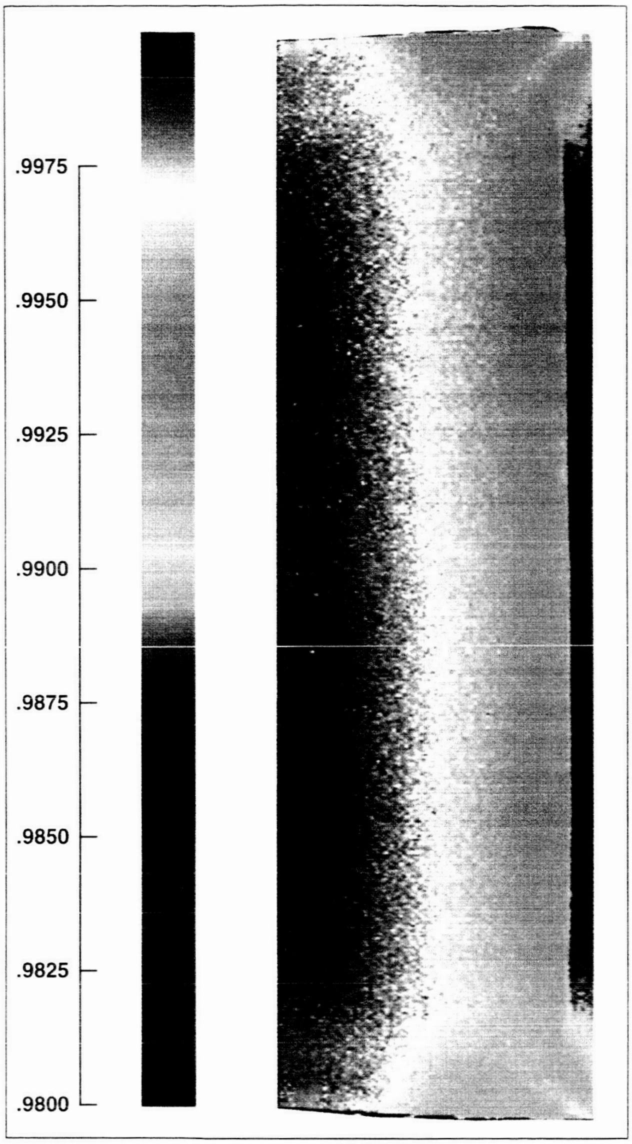

Fig. 1. PSP-measured pressure field on NACA 0012 wing: angle of attack 5 degrees, velocity 30 meters per second.

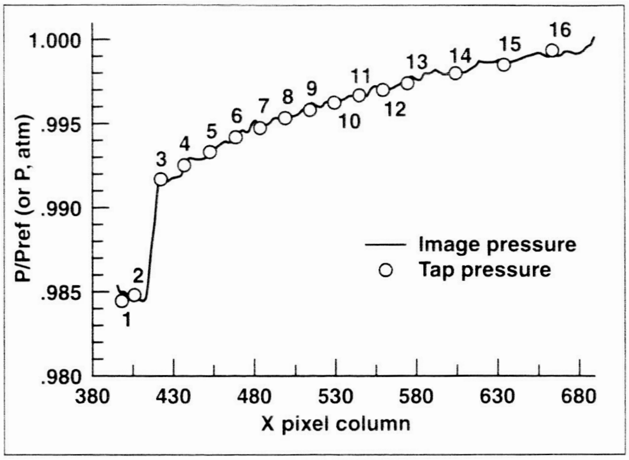

Fig. 2. PSP-measured pressure field versus pressure-tap data.

The first figure shows the pressure field on the NACA 0012 wing at 30 meters per second and at an angle of attack of 5 degrees. The pressure scale is in atmospheres, with the airflow from right to left in the image. The second figure displays the pressures measured by the PSP on the airfoil from leading edge to trailing edge, compared with pressures measured using conventional pressure taps. The root-mean-square error between tap and calibrated PSP pressures is 21.8 pascals (0.04 coefficient-of-pressure units).

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